

UNDERWATER HEARING IN MAN:

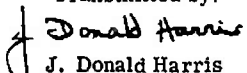
II. A Comparison of Temporary Threshold Shifts
Induced by 3500 Hertz Tones in Air and Underwater

by

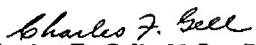
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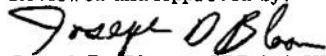
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SUMMARY PAGE

THE PROBLEM

To explore the upper limits of useful hearing by underwater swimmers.

FINDINGS

Man's underwater hearing threshold at 3500 Hertz is about 70 decibels higher than his threshold in air. This study shows that a similar difference exists in the ability of 3500 Hertz pure tones to produce temporary threshold shifts in the two media.

APPLICATION

These findings contribute to the determination of the characteristics of underwater hearing in man.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9012D - Physiological Psychology of the Ear under Stress. The present report is No. 5 on this work unit, and is the second in a series titled Underwater Hearing in Man. The first in this series was SMRL Report No. 569 (Feb 1969) and concerned Sensitivity. The present report was approved for publication on 15 January 1970 and designated as Submarine Medical Research Laboratory Report 608. A portion of this research was performed under ONR Contr. No. N00014-67-C-0046 with Connecticut College.

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ABSTRACT

Six men were subjected to 3500 Hertz pure tones of 1250 millisecond pulse length repeated every 2.5 seconds for a period of 15 minutes at Sound Pressure Levels of 168 and 178 decibels re .0002 dynes per square centimeter. Temporary Threshold Shifts were measured and compared to temporary threshold shifts induced by similar exposures at lower levels in air in a second group of five men. It was found that the Sound Pressure Level of 3500 Hertz tones in water must be about 68 decibels higher than tones in air in order to induce comparable magnitudes of temporary threshold shifts.

UNDERWATER HEARING IN MAN: II. A COMPARISON OF TEMPORARY THRESHOLD SHIFTS INDUCED BY 3500 HERTZ TONES IN AIR AND UNDERWATER

I. INTRODUCTION

Underwater threshold sensitivity of swimmers has been determined¹. In general, man's sensitivity to sound pressure is reduced some 40 to 70 decibels upon submersion in water. Montague and Strickland², have shown that this reduced sensitivity is accompanied by an increased tolerance to intense sound pressures at 1500 Hertz (Hz). Their data are shown in Figure 1. The procedure used by Montague and Strickland was to increase the sound pressure of pure tones from moderate levels to a point beyond which the divers refused to be exposed. Thus, their findings are based on the subjective reactions of the divers to the sound. It is well known that tolerance to intense sound is highly variable. A more objective and stable measure of the effects of intense sounds on listeners is the temporary threshold shift (TTS) resulting from the exposure.

Montague and Strickland measured TTS some five minutes following exposure and reported an average threshold shift of 7 and 6 dB at 3000 and 4000 Hz respectively. These measurements were made after the divers had been through four brief series during which the 1500 Hz signals were varied some 20 dB in intensity. Since each diver could terminate the series the resulting exposures differed across divers. Some divers would not tolerate more than 165 dB while some would tolerate more than

175 dB. Consequently, it is difficult to interpret the threshold shifts which did occur, or to generalize the findings to other stimulus conditions.

The experiment described below was undertaken to explore the upper intensity limit of useful underwater hearing by comparing TTS produced by exposure to intense underwater signals with TTS produced by comparable stimuli in air. It is of further interest to determine whether the magnitude of the difference in threshold sensitivity of the ear in air as compared to underwater is the same as the magnitude of the differences in the effects of intense stimuli on the ear in the two media.

II. METHOD

Subjects. The subjects for the underwater conditions of this experiment were six young men who had normal air conduction hearing levels. None of these men were experienced divers. The subjects for the airborne conditions were five male laboratory assistants or researchers who also had normal hearing levels.

Apparatus. Intense signals were created underwater in a 25 meter swimming pool with the apparatus sketched in Figure 2. A Hewlett-Packard Model 200

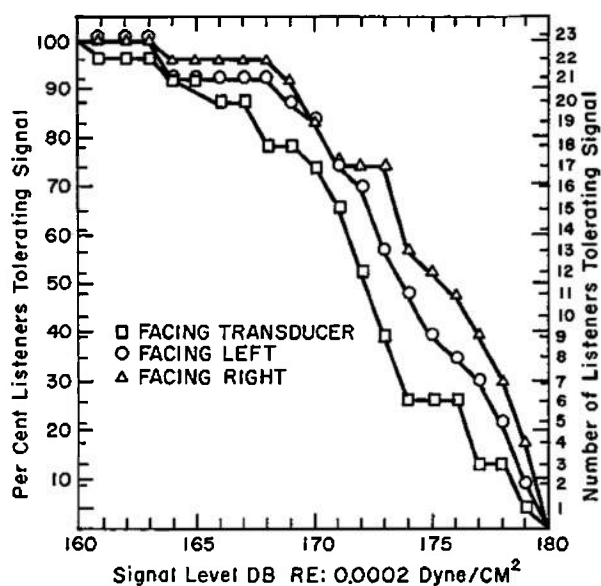


Fig. 1. Limit of tolerance of high-level underwater sound at a frequency of 1500 Hertz. From Montague and Strickland².

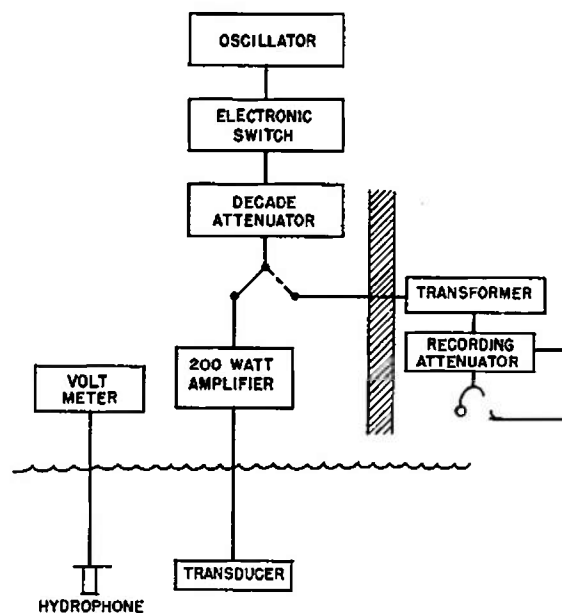


Fig. 2. Experimental apparatus for producing intense underwater signals and measuring the resulting temporary threshold shifts.

ABR oscillator generated a 3500 Hz signal which was gated by a Grason-Stadler 829E Electronic Switch with a rise-fall time of 10 milliseconds, pulse length of 1250 milliseconds and an on/off ratio of 1.00 (50% duty cycle). A Hewlett-Packard model 350D decade attenuator controlled the level of the signal input to the McIntosh model M1200AB 200 watt amplifier. The amplifier drove the underwater transducer which was a loaded bar mass having a resonant frequency of 3700 Hz. Transducers of this type are described briefly by Albers³. The transducer was mounted on the bottom of the pool with its active plate about 18 inches below and facing the water surface. Underwater sound pressures were measured with Naval Underwater Sound Laboratory type XU-1295 hydrophone and a Ballantine battery operated vacuum tube voltmeter.

For airborne conditions, similar apparatus was used, but the output of the decade attenuator was fed directly to a telephonix TDH-39 earphone. In both the underwater and air cases, pre- and post-exposure thresholds were measured with a Grason-Stadler E3262A recording attenuator. Thresholds were measured for a 250 msec, 50% duty cycle tone at 4 kHz only.

Procedure. Each subject was tested individually. Following measurement of pre-exposure air conduction threshold, the underwater subject donned a diving face mask and entered the pool at a point where the water was five feet deep. Using a snorkel tube for breathing, the subject placed his chin on a chin rest which positioned his head just below the surface with his face about six inches from the face of the transducer. The subject was then exposed to 3500 Hz pure tones at average Sound Pressure Levels (SPL) of 168 or 178 decibels (dB) re .0002 dyne/cm² for a period of fifteen minutes. Upon completion of the exposure, the subject was removed from the pool and taken to an adjoining room for post-exposure threshold measurements.

The measure of interest is, by convention, the TTS existing two minutes following the exposure (symbolized TTS₂). In all cases it was possible to obtain this measure directly. However, since a TTS at any given moment is highly variable, the TTS on either side of the two minute point is also considered in estimating TTS₂. To obtain the most stable estimate, data were taken only on one ear of each subject. In all cases, this was the subject's most sensitive ear. TTS₂ was calculated by subtracting pre-exposure threshold levels from two minute post-exposure threshold levels. All subjects in the underwater conditions received the two exposure levels with an interval of at least twenty-four hours separating exposures. Two subjects received an additional exposure at an SPL of 173 dB re .0002 dyne/cm². The remaining four subjects were run in a control condition in which no stimuli were presented. These subjects were told that the frequency had been raised to very high levels that were inaudible but might nevertheless produce TTS.

For the airborne conditions the procedure was similar except that the SPL of the fatiguing stimuli

were 85, 95, and 105 dB re .0002 dynes/cm² delivered by earphone.

As one would expect, it was extremely difficult to achieve stable stimulus conditions in the highly reverberant pool with a high intensity source broadcasting into a pressure release surface hardly more than a wavelength away. The location selected was determined by trial and error procedure during which 16 men (other than those described earlier) were exposed to SPL's which averaged between 164 and 179. The actual levels however, varied considerably during, as well as between, trials. Eventually, a spot was found where the standing wave pattern was reasonably consistent from trial to trial and levels could be more or less reliably replicated. The SPL's reported earlier are averaged values measured around the subjects' heads during exposure.

III. RESULTS AND DISCUSSION

Of the 16 men exposed in trial and error period, none incurred alarming TTS. The range of TTS₂ was from 0 to 22 dB with a mean of 17 dB. None reported any serious discomfort.

Median TTS₂ resulting from the controlled underwater and in air exposure conditions is plotted in Figure 3. The separation of the lines drawn

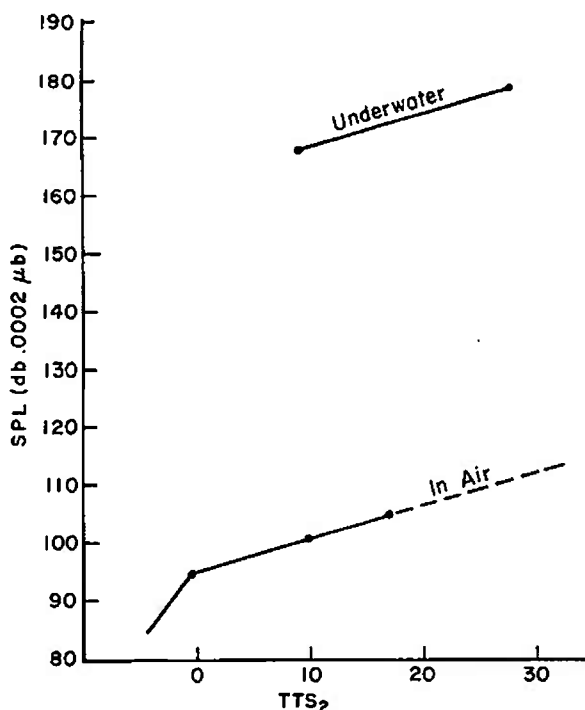


Fig. 3. Median temporary threshold shift existing two minutes after exposure to 3500 Hertz tones in air and underwater.

through the data points indicates that the difference in SPL's which would produce equal magnitudes of TTS₂ in air and underwater is about 68 dB. This is comparable to the difference in threshold sensitivity at 3500 Hz of the human ear in the two media¹. Only one diver reported an "oculo-gyral effect" similar to that described by Montague and Strickland. This one subject reported that during the highest SPL condition his visual field was disturbed. He also reported that his head was pushed to the right slightly when the sound came on. The first author in subsequent explorations also experienced this effect, but only slightly. By placing one's chin within an inch or so of the face of the transducer, one could feel a definite force which tended to twist the head to the right or left depending on initial orientation. Some occasional displacement of the visual field was also experienced. Only once, with the side of the head almost resting on the transducer was there any sensation akin to aural pain. None of the twenty subjects complained of pain or reported the sound as unbearable, although it was referred to as annoying or uncomfortable by some. Some, however, reported losing awareness of the sound as they became engrossed in their thoughts (or day dreams). We feared, in fact, that one subject had fallen asleep during the session. It was clear that these subjects would have tolerated somewhat higher SPL's.

Montague and Strickland found that their procedure yielded tolerance levels 40-50 dB above similar data for airborne exposure. Depending somewhat on the orientation of the divers to the sound source, 50% of their divers refused to be exposed to levels above 172-175 dB SPL at 1500 Hz. However, subjects in the present study were subjected to 178 dB SPL at 3500 Hz for a full fifteen minutes. Underwater hearing sensitivity is shown in Figure 4 to be frequency dependent, with thresholds at 1000 Hz being considerably lower than at 4000 Hz¹. It would appear that a similar slope to the so-called threshold of pain could explain the difference between Montague and Strickland's data and those reported here.

Montague and Strickland have also shown that a considerable amount of sound attenuation is provided by foam Neoprene Arctic hoods - a result we have confirmed as shown in Figure 5. They also found that the hood afforded some protection from high intensity sound, but were unable to test this completely.

Smith⁴ found that two divers wearing hoods could work for at least thirty minutes in the presence of 1900 Hz signals at 169 dB (700 millisecond pulse length, 5% duty cycle) without incurring a threshold shift or feeling any discomfort. At this level 25 percent of Montague and Strickland's subjects terminated bare headed exposure.

It may be concluded that at 3500 Hz the difference in SPL in air and underwater required to produce equal magnitudes of TTS₂ is comparable to the difference in SPL at threshold level in the two media. It also appears, from a comparison of this study with that of Montague and Strickland, that the tolerance limits at 3500 Hz may be greater than 1500 Hz.

Further research would test this directly by comparing TTS₂ induced by signals of various frequencies. It does appear, however, that the dynamic ranges of the ear in air and underwater are comparable.

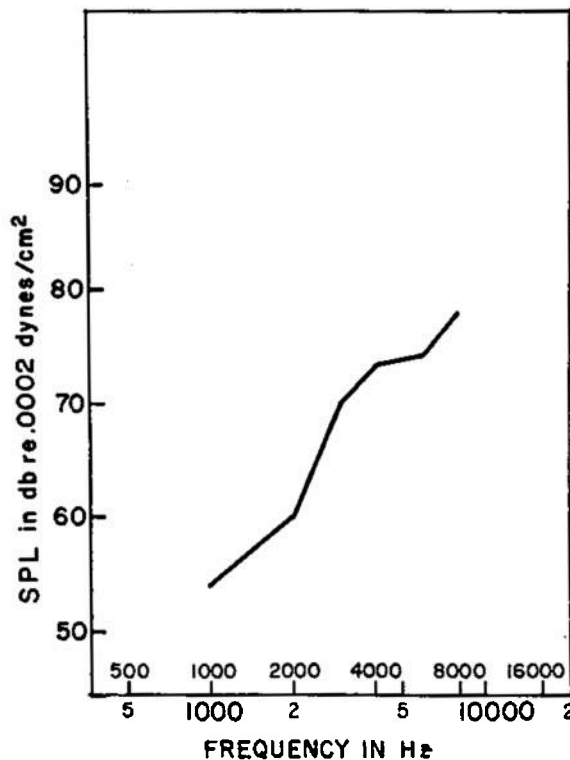


Fig. 4. Underwater hearing thresholds for eight men with normal AC and BC hearing levels. From Smith¹.

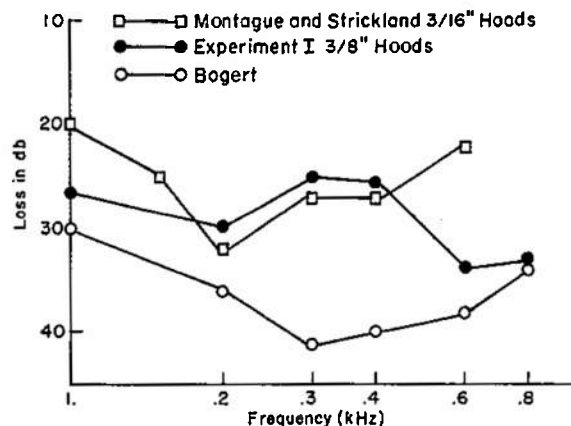


Fig. 5. Attenuation provided by divers hoods. A comparison of three studies. From Smith¹.

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